Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Antenna: a key enabler for 5G innovative RFIC development

By

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STMicroelectronics, Technology R&D, Silicon Technology Development, Crolles, France

Abstract: - This is a review talk discussing the context and requirements of 5G. It examines the tendency towards Small Cell and HetNets, as well as the challenges of Backhaul and Fronthaul. Next, it turns to BiCMOS/CMOS mmW ICs, and the push towards integration. It argues that low cost mmW antennas as the missing enabling technology, and identifies the need to develop Innovative High Gain mmW antennas. Some conclusions and perspectives also are included.

Keywords: - 5G, Small cells, HetNets, mm wave ICs, mm wave antennas

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Antenna: a key enabler for 5G innovative RFIC development

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Monday, November 10th

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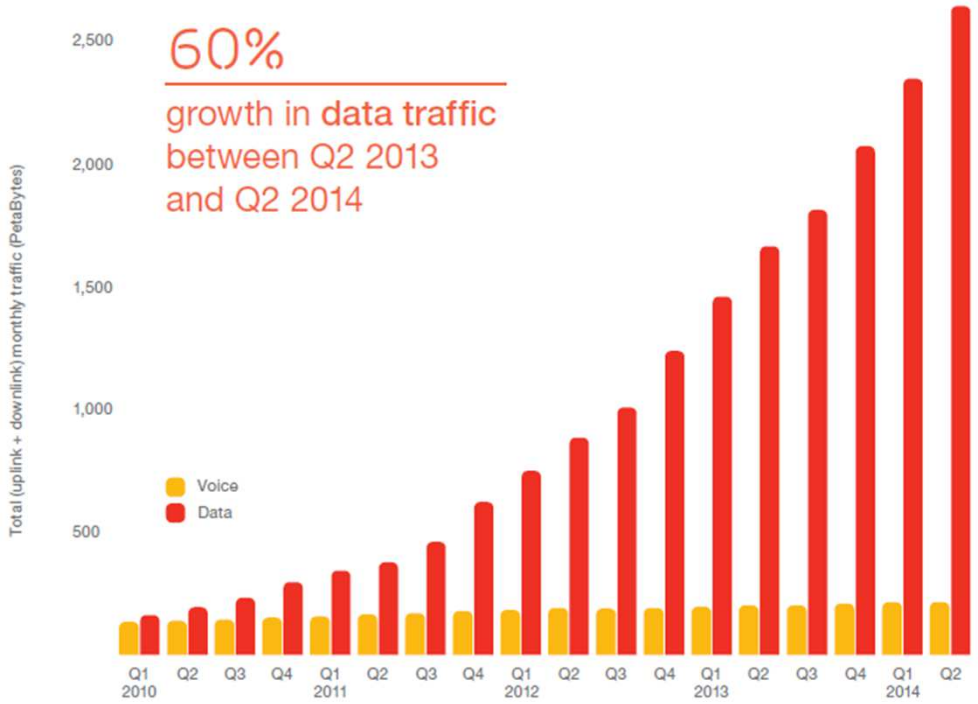
2014 Loughborough Antennas & Propagation Conference

Outline

- 5G Context & Requirements
- Towards Small Cell and HetNets
- The Backhaul and Fronthaul Challenge
- BiCMOS/CMOS mmW IC: pushing integration
- Low cost mmW antennas: the missing enabling technology
- Innovative high gain mmW antennas
- Conclusion and perspectives

5G Context

- Following the growth of mobile devices, *global mobile data traffic* is booming and has exceeded *2.5 Petabytes/month* in *2Q14* (*up 60%* year-over-year).



Ericsson mobility report August 2014

- In order to *address consumer demand*, the development of *high speed*, *low cost* and *low power wireless technologies* *is a key challenge for our industry*.

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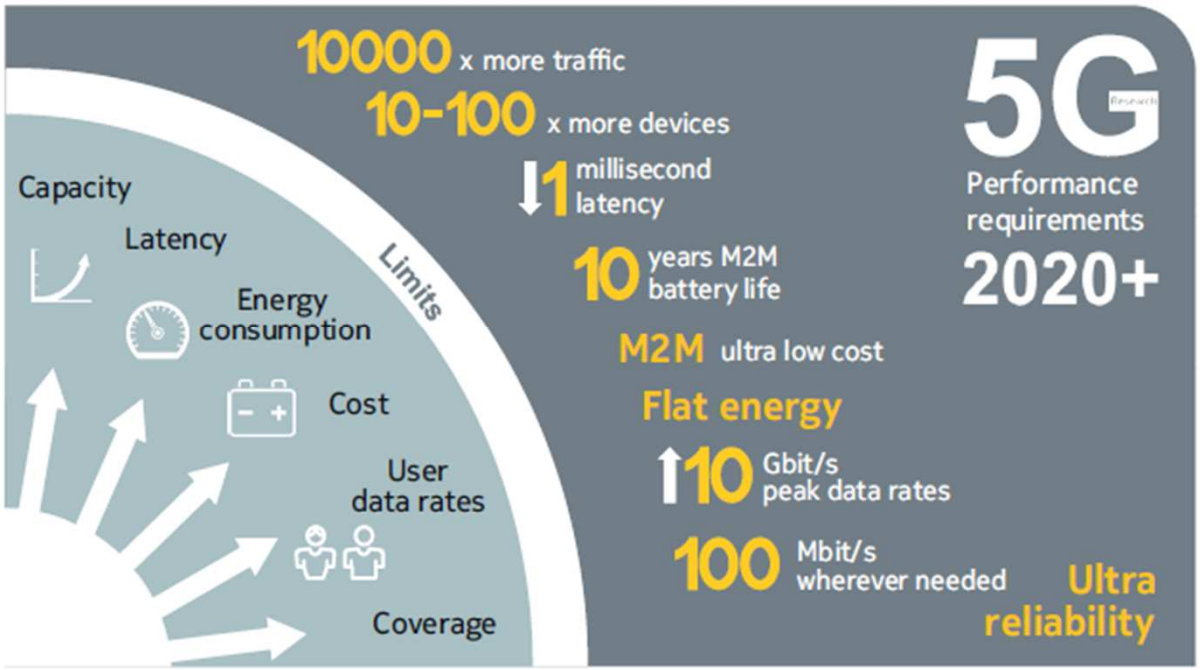
5G Requirements

- A main objective of 5G is to be able to handle the traffic required in 2020.



5G Use Cases and Requirements, FutureWorks NSN White paper April 2014

- Peak data rates of 5G will be higher than 10 Gbit/s but more importantly the cell-edge data rate should be 100 Mbit/s. This will allow the use of the mobile Internet as a reliable replacement for cable wherever needed.

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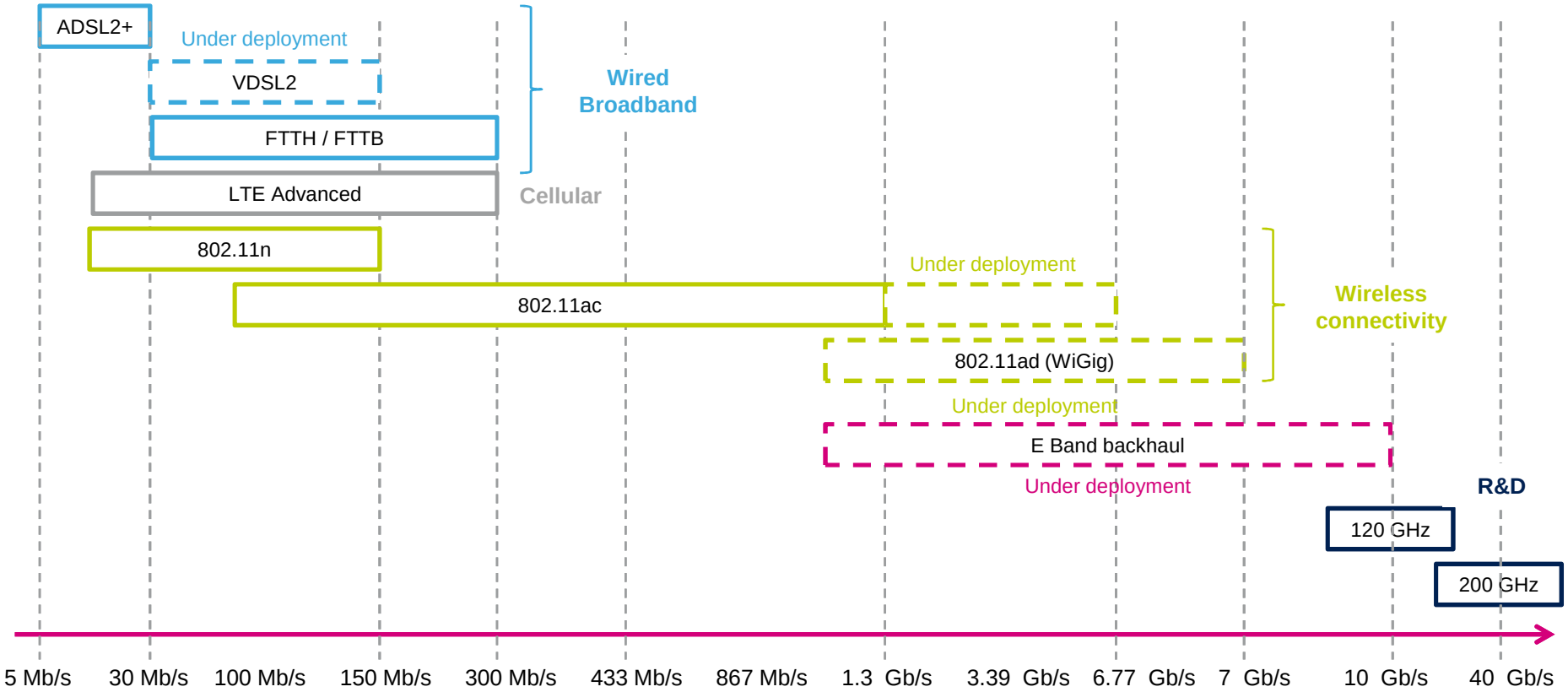
5G: improving data rate or capacity ?

- Many current 5G researches are dealing with new RF / mmW radio technologies for access in order to increase peak data rates, but do we really need new radio technologies for acces?



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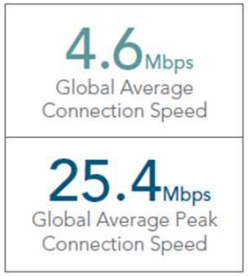
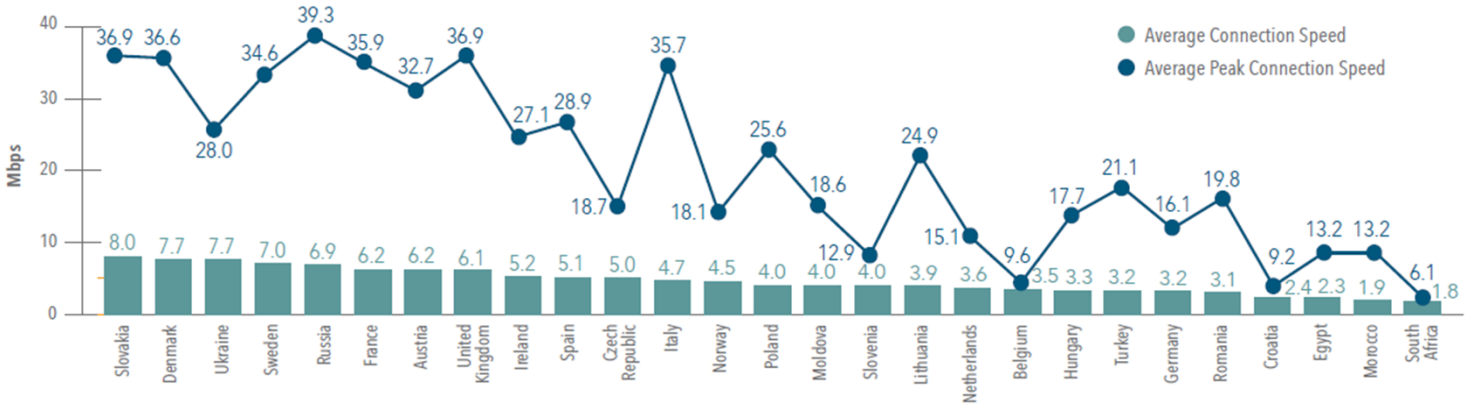
5G: improving data rate or capacity ?

- Today average fixed broadband connection speed in Europe is 4.6 Mb/s (best in class is ~14 Mb/s), which is far lower to the Gb/s experience that WiFi can deliver today …



- The situation is not better from mobile average connection speed which is in Europe ~4 Mb/s (best in class is ~8 Mb/s).



Akamai State of the Internet Report Q2 2014

- While 100s Mb/s & Gb/s wireless technologies are today available in a cost effective manner (e.g. 802.11ac & LTE), we are not able to deliver this experience to the user: this is the challenge that 5G has to address.

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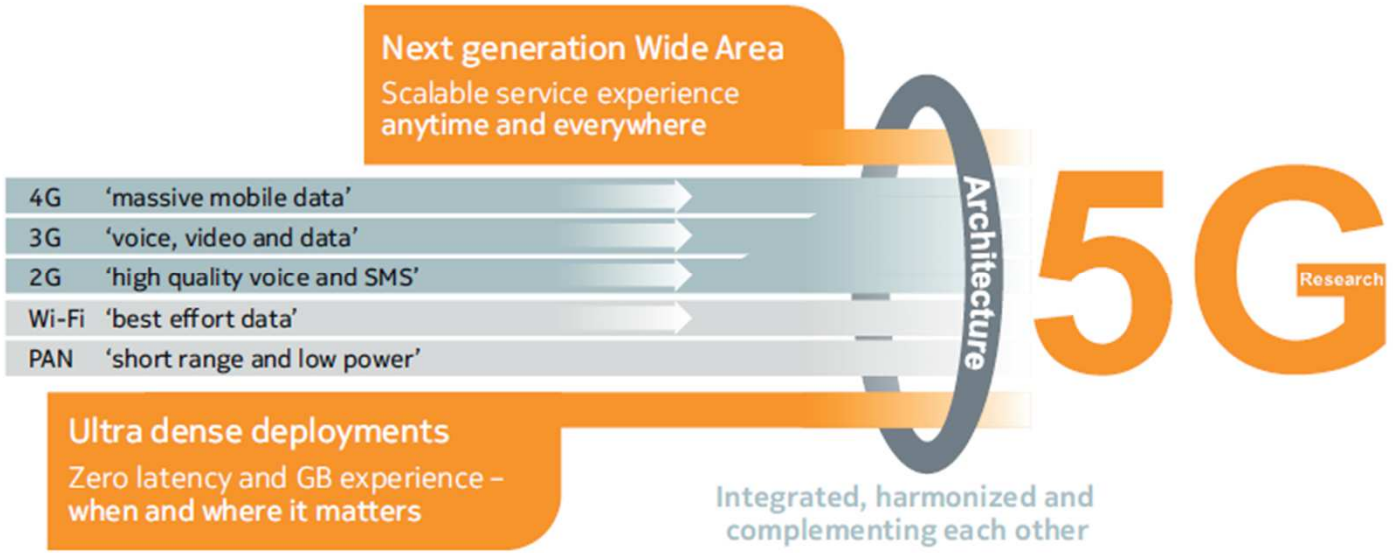
5G: Towards Seamless Integration

- So 5G is more related to the symbiotic integration of existing wireless technologies rather than the development of new RF / mmW radio technologies for access.



5G Use Cases and Requirements, FutureWorks NSN White paper April 2014

- But this does not mean that new radio technologies are not required, as we will discuss later in order to increase network capacity the requirement is more on fronthaul / backhaul side.

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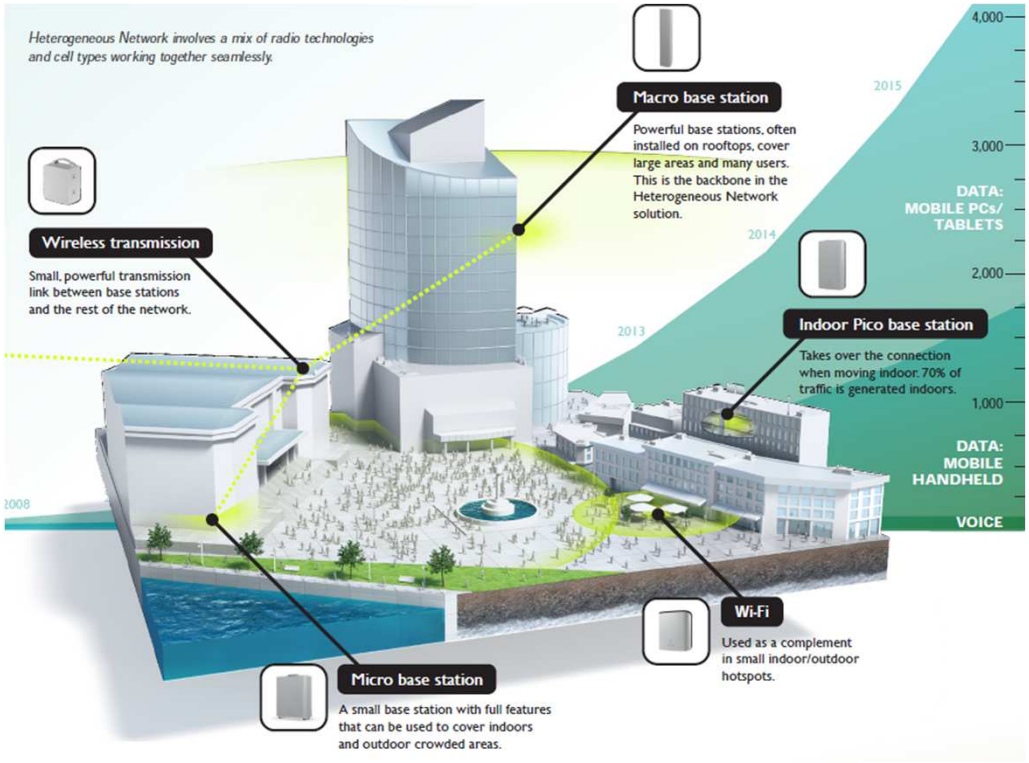
Towards 5G Heterogeneous Networks

- Since increasing the capacity of existing sites has a limit, we are now moving to the introduction of lower power RBS covering smaller area (small cells) as well as the integration of WiFi with LTE to deliver Heterogeneous Networks (HetNets)



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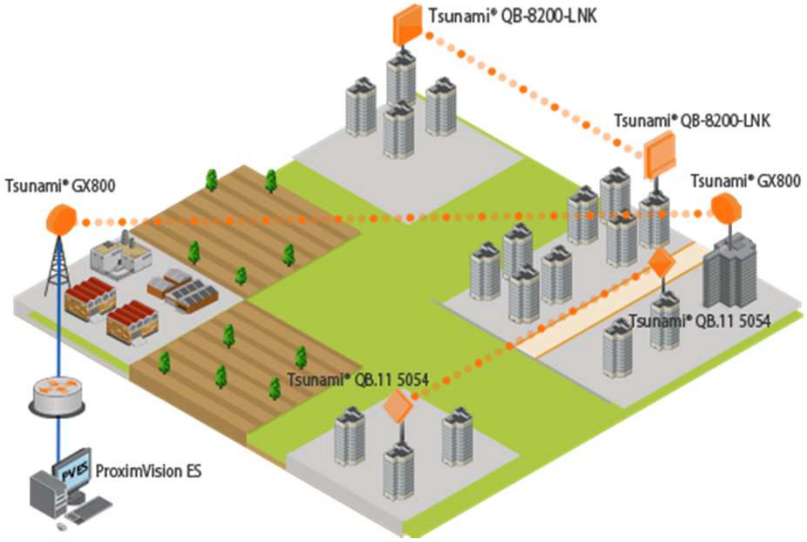
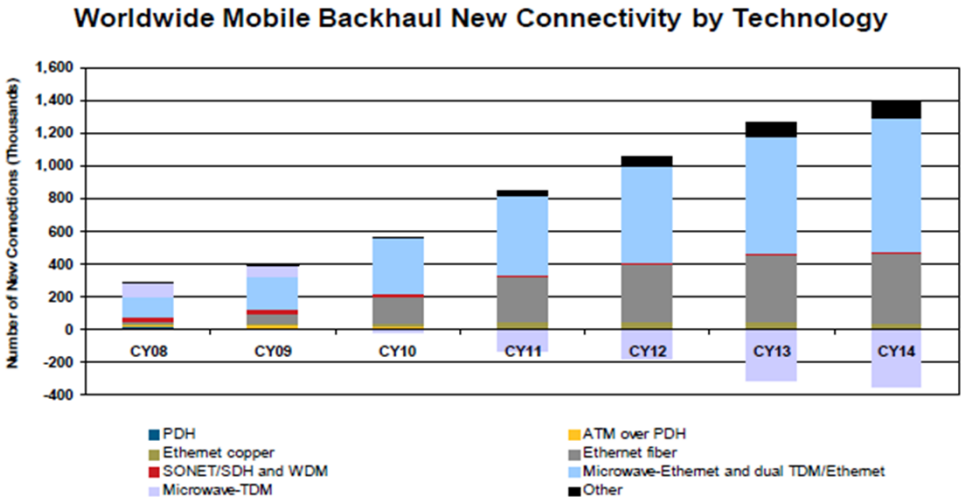
Wireless Backhaul Challenge

- So *small cells* will play a key role in order to *increase the network capacity*.
- But backhaul connection is an issue since civil works cost can limit the deployment of small cells: *wireless backhaul* is here *mandatory*.





- Since *high data rates* (1 Gb/s in full duplex) are required *at low cost*, *60 GHz* & *70-80 GHz* wireless backhaul solutions are *considered* today for wireless backhaul.

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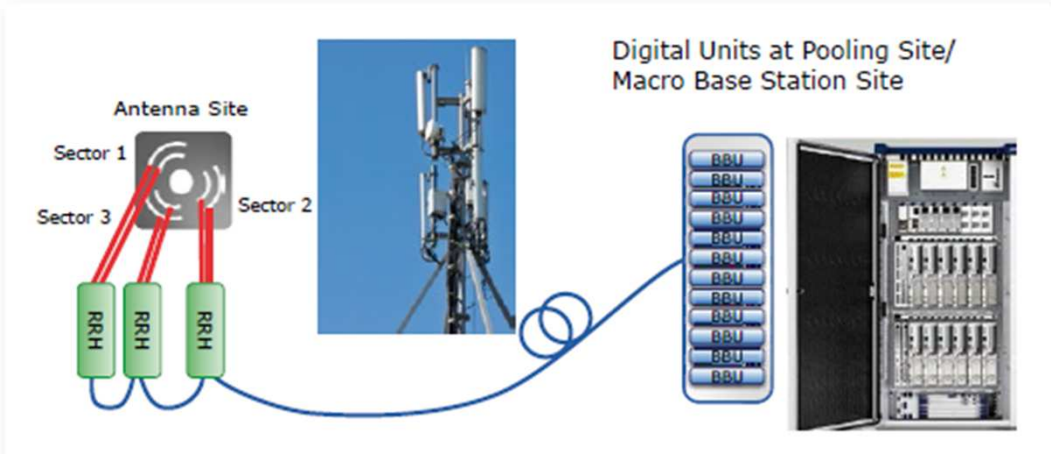
C RAN: New Constraints on Fronthaul

- Moreover, in order to improve networks performances and power efficiency, Centralized RAN is currently promoted by equipment vendors.



ADVA optical networking - Fronthaul Networks – a Key Enabler for LTE-Advanced

- While the concept of pooling base band resources is appealing, it puts some pressure on the fronthaul connection between the Remote Radio Head and the centralized base band site.

Wireless Fronthaul Challenge

- More specifically, the CPRI interface use to connect RRH to the centralized base band site is requiring up to 10 GbE data rates and distance up to 40 km.

Application	Channels	Antenna Configuration	CPRI Line Rates
WCDMA	4 x 5 Mbit/s	1 sector, MIMO 2x2	1228.0 Mbit/s
LTE	20 Mbit/s	1 sector, MIMO 2x2	2457.6 Mbit/s
WCDMA LTE	1 x 5 Mbit/s 20 Mbit/s	3 sector, MIMO 2x2	9830.4 Mbit/s

ADVA optical networking - Fronthaul Networks – a Key Enabler for LTE-Advanced

- Optical technologies should be the technology of choice to address such specifications, but keep in mind that we are dealing with an increased number of RRH (small cell) to be integrated in dense urban environment.
- Since the network has to be deployed in a cost effective manner, the deployment of fiber fronthaul solution will be an issue and a low cost mmW wireless solution is here highly desirable (as explained previously for backhaul)

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60 GHz Low Cost PtP: Motivation

- In order to address those wireless backhaul and fronthaul challenges, new mmW frequency bands are considered. 60 GHz bands is a good example:
  - **Licensing costs**:

    Regulators are allocating the *60 GHz spectrum* on a *license free* or *light licensing* basis
  - **Spectrum availability**:

    7 GHz of bandwidth available worldwide enable *simple modulation* to achieve *high data rate*
  - **Frequency re-use**:

    Thanks to *oxygen absorption @ 60 GHz* and related short distance link
  - **60 GHz backhaul is a proven path**:

    Orange Austria is using 90 wireless *backhaul bridges* working *at 60 GHz* (in LOS configuration) to support an *LTE metrocell in Vienna* (via a partnership with Alcatel-Lucent)

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Existing 60 GHz Wireless Backhaul solution

- Some *60 GHz wireless backhaul solutions* are *already available on the market*.

Siklu

ETHERHAUL-600

Sub10

LIBERATOR-V320

Ericsson

MINI-LINK PT3060

Bridgewave

AR60

Ceragon

FibeAir-10060

Proxim

Tsunami® QB-62000

- But *price point remains high* (~20 k$) …

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mmW PtP: The Economical Challenge

- While required wireless mmW link are technically feasible, the challenge is here more on integration in order to propose a real breakthrough on the cost of proposed solution (which is mandatory to deployed denser networks):

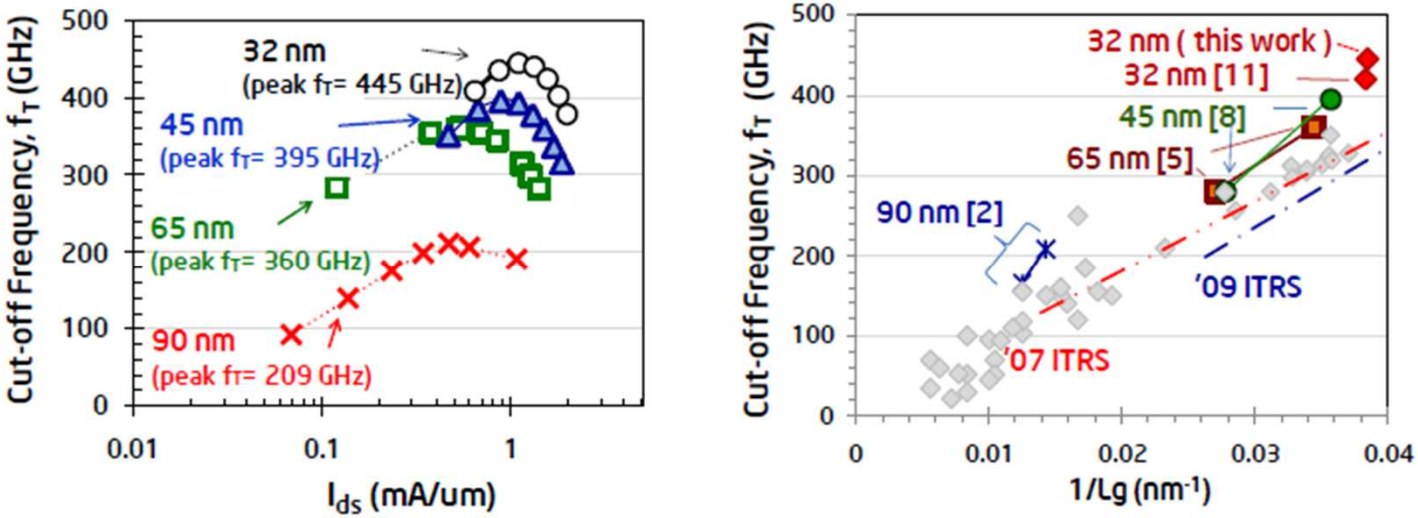
Today ~25000 $

Tomorrow ~1500 $?

- This is where *silicon technologies* and development such as *WiGig can play a role*.

CMOS / BiCMOS Technology at mmW

- Following Moore's law, *silicon transistor RF performances* is improving and achievable performances are now *compliant* with most of *mmW commercial applications*.



C.H. Jan et al., "RF CMOS Technology Scaling in High-k/Metal Gate Era for RF SoC (System-on-Chip) Applications", IEEE International Electron Devices Meeting (IEDM), 6-8 Dec. 2010

- We can then think about *leveraging silicon* technologies *integration capability* in order to develop innovative and *cost effective mmW chipset solution*.

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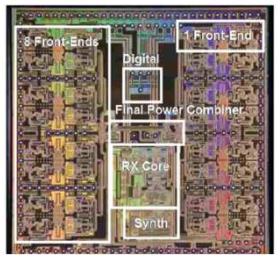
CMOS / BiCMOS 60 GHz ICs

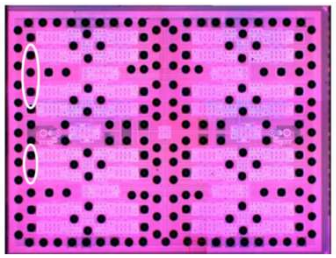
- As an example, several *60 GHz chipset* solutions have been developed, demonstrating the possibility to use *silicon technology* to address mmW wave applications.

IBM / Mediatek



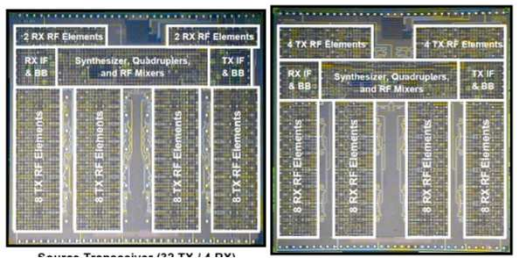
A. Valdes-Garcia et Al., "A SiGe BiCMOS 16-Element Phased-Array Transmitter for 60GHz Communications", IEEE ISSCC 2010

Intel



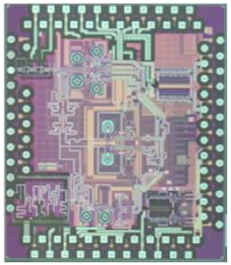
E Cohen et Al., "A thirty two element phased-array transceiver at 60GHz with RF-IF conversion block in 90nm flip chip CMOS process", IEEE RFIC 2010

SiBeam



S. Emami : "A 60GHz CMOS Phased-Array Transceiver Pair for Multi-Gb/s Wireless Communications ", IEEE ISSCC 2011

ST



A. Silligaris, "A 65nm CMOS Fully Integrated Transceiver Module for 60GHz Wireless HD Applications ", IEEE ISSCC 2011

- In addition, a *main challenge* has concerned the development of *low cost 60 GHz antenna technology* cleverly combining:
  - Antenna achieving acceptable performances (~5 dBi gain, 80° aperture, …)
  - Low loss and low cost mmW packaging technology
  - Assembly strategy compliant with industrial constraints (volume production)

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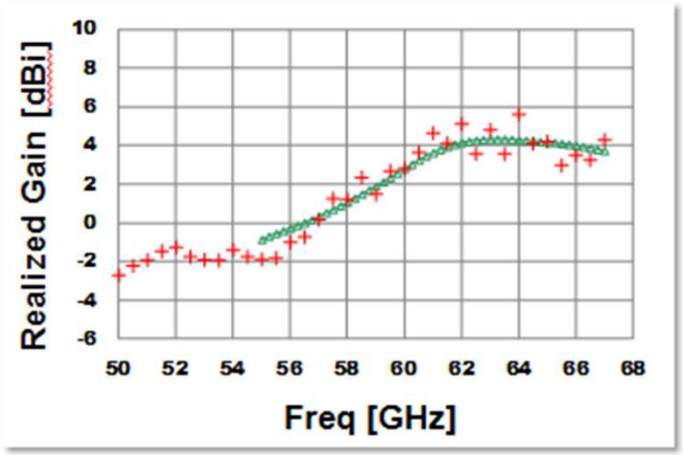
Low Cost 60 GHz Packaging and Antennas

- Leveraging the availability of low *loss material*, classical BGA technology has been used to develop low cost antenna in package solutions.
- Performances of antenna integrated on low loss BGA technology are today *competing with* previous *HTCC/LTCC* proven solutions:

60 GHz antenna performances achieved in mmW HDI organic technology:

Measured realized gain:

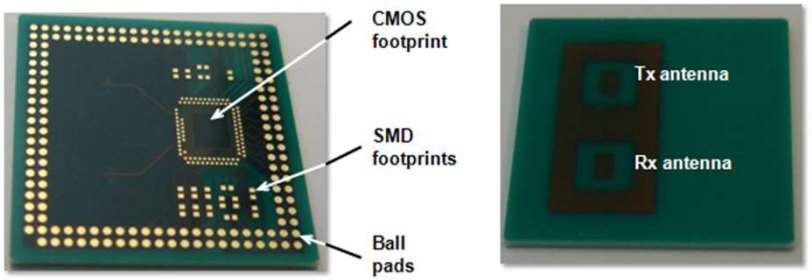


Sources: STMicroelectronics

60 GHz mmW HDI organic package with integrated antennas:

Top side:

Bottom side:



R. Pilard, "HDI Organic Technology Integrating Built-In Antennas Dedicated to 60 GHz SiP Solution", IEEE AP-S 2012

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Backhaul Business Opportunity for WiGig Chipset Manufacturers

- *Leveraging WiGig* chipsets, *low cost 60 GHz backhaul* solution is not so far away:

Existing 60 GHz Backhaul Systems :

- Max Output power (at antenna port): *~10 dBm*
- Modulation scheme /sensitivity:
  - *QPSK* / *-62 dBm*
- Antenna Gain: ***~38 dBi***
- Data rates:
  - *100 Mbps*
  - 300 Mbps
  - *1000 Mbps*
- Range: from *500 m* up to *1.5 km*
- Duplex mode: TDD & FDD

WiGig 60 GHz Systems :

- Max Output power (at antenna port): *~10 dBm*
- Modulation scheme /sensitivity:
  - ∏/2 *BPSK* (MCS-1) / *-68 dBm*
  - ∏/2 BPSK (MCS-5) / -62 dBm
  - ∏/2 QPSK (MCS-6) / -63 dBm
  - ∏/2 *QPSK* (MCS-9) / *-59 dBm*
- Antenna Gain: ***~5 dBi***
- Data rates:
  - *385 Mbps* (MCS-1, single carrier)
  - 1251.25 Mbps (MCS-5 , single carrier)
  - 1540 Mbps (MCS-6, single carrier)
  - 2502.5 Mbps (MCS-9, single carrier)
- Range: from *1 m* up to *10 m*
- Duplex mode: TDD

- It seems to be *all about antennas* performances.

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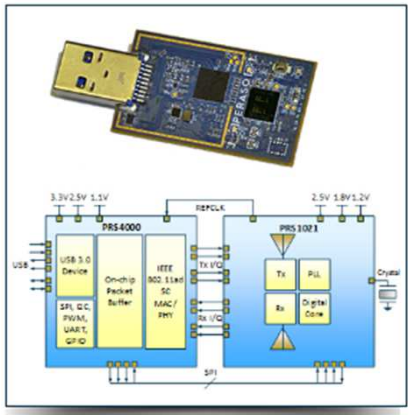
Low Cost mmW Antennas: the missing enabling technology

- Unfortunately, while necessary the *availability* of cost effective *silicon mmW chipset solution* will *not* be *enough* in order to reduce the cost of backhaul / fronthaul solution:

60 GHz BiCMOS chipset ~5$
Peraso PRS1021 (>100 000 parts)



SMPM connector ~15$
67 GHz board connector

V band antenna ~300/1000$

- *Low cost* high gain *mmW antenna* solution is a *key enabler* in order to support the development of *cost effective backhaul / fronthaul solution* that can leverage the integration capability and cost effectiveness of *silicon* technologies.

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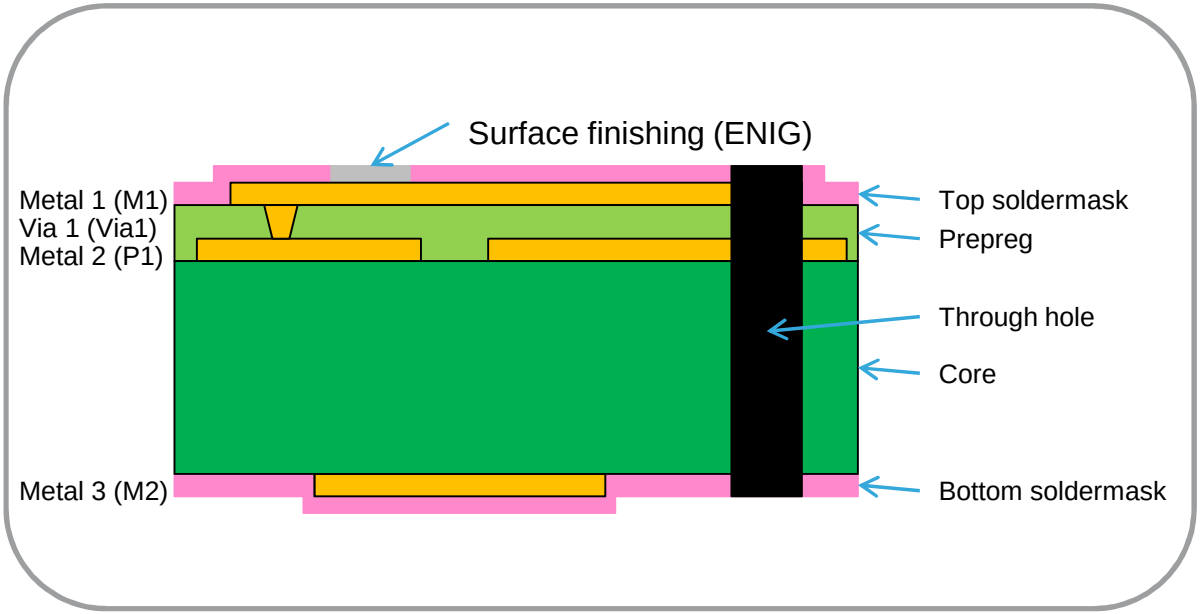
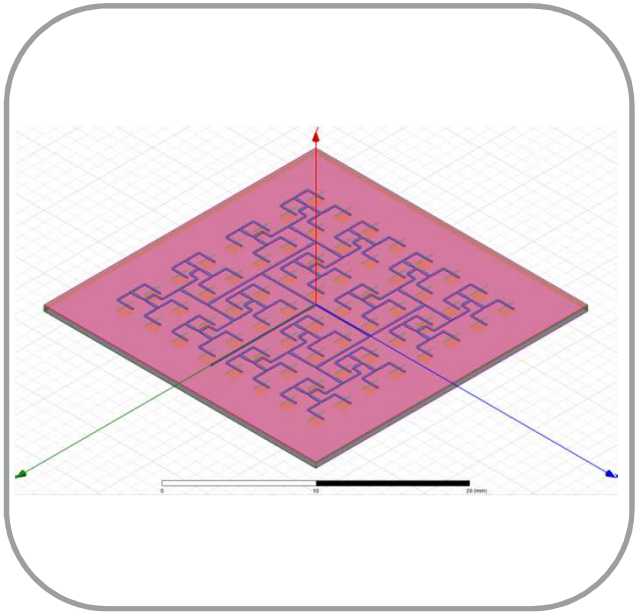
Low Cost 60 GHz Planar Array Integrated in HDI PCB Technology

- In order to develop innovative and *low cost high gain mmW antenna* solution, we can try to develop a *planar antenna array* solution using available *low loss PCB technologies* (leveraging WiGig BGA and backplane low loss PCB developments):

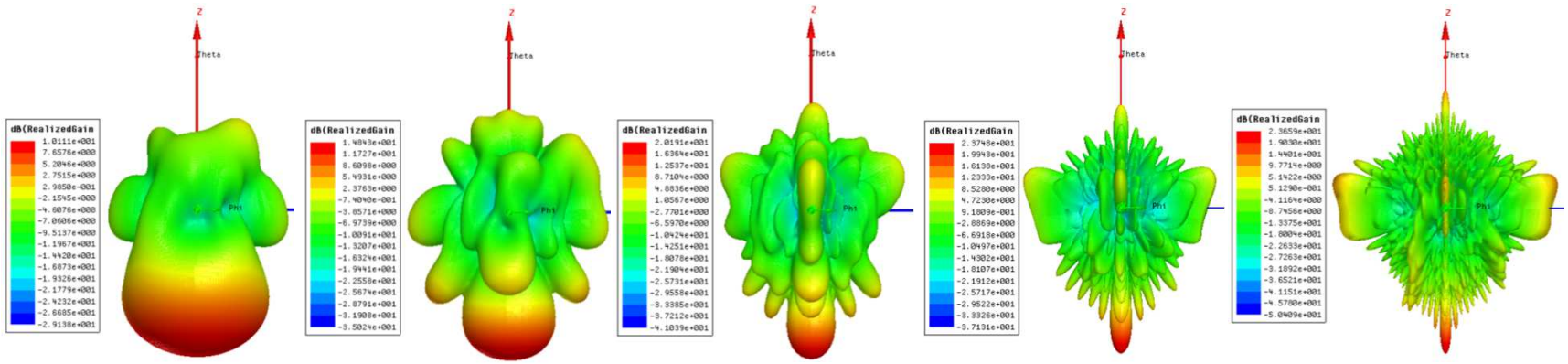
PCB Cross-Section:



Planar Antenna Array



Low Cost 60 GHz Planar Array Integrated in HDI PCB Technology



2x2 array:	4x4 array:	8x8 array	16x16 array:	32x32 array:
Gmax = 10.1 dBi	14.8 dBi	20.2 dBi	23.7 dBi	23.7 dBi
$HPBW_E$ = 48°	30°	14°	8°	3.5°
SLL_E = 24 dB	12 dB	14 dB	13 dB	12 dB
η_{tot} = 87 %	77 %	63 %	40 %	16 %
Area = 10 mm x 15 mm	15 mm x 22,6 mm	25 mm x 32,6 mm	45 mm x 50 mm	85 mm x 90 mm

- Unfortunately, *beyond* an antenna array size of *8x8*, we *lose* too much *energy in the feeding network* and then it seems *impossible to achieve gain exceeding 23 dBi* only using a planar array.

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Low Cost and 3D Printed 60 GHz Plastic Lenses

- Since *mmW backhaul* / fronthaul applications require *high antenna gain* (>30 dBi), a *planar antenna array* will *not* be *enough* (feeding network loss limits the maximum achievable gain).

- Consequently, a *low cost lens* solution could be an appealing *solution*. *What about* using *3D printing plastic technology* to do this (instead of costly Teflon approach) ?

ABS-M30

Electrical Properties[3]	Test Method	Orientation	Value Range
Volume Resistivity	ASTM D257	XZ Axis	4.0^{15} - 3.3^{15} ohm-cm
Dielectric Constant	ASTM D150-98	XZ Axis	2.6 - 2.86
Dissipation Factor	ASTM D150-98	XZ Axis	0.0048 - 0.0054
Dielectric Strength	ASTM D149-09, Method A	XZ Axis	100 V/mil
Dielectric Strength	ASTM D149-09, Method A	ZX Axis	360 V/mil

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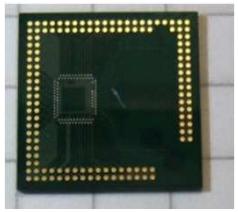
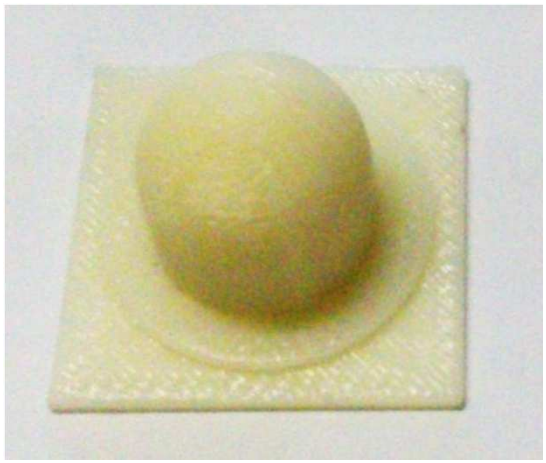
Low Cost and 3D Printed 60 GHz Plastic Lenses

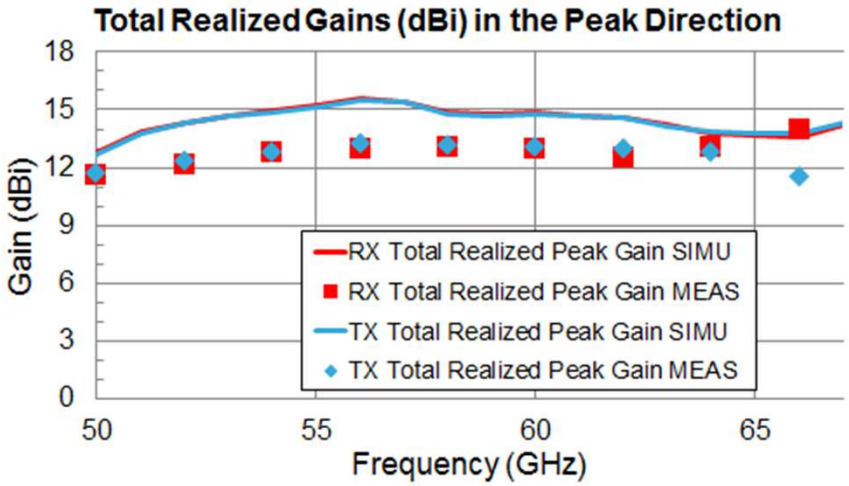
- Leveraging a previously developed WiGig BGA module, a *plastic lens prototype* has been *manufactured* using *3D printing*.
- *Achieved performances* are *in line with simulation* (8 dBi gain improvement), paving the way of *cost effective high gain 60 GHz antenna* solution development.

60 GHz BGA and plastic lens prototype:





Measured gain:



A. Bisognin et al, "3D Printed Plastic 60 GHz Lens: Enabling Innovative Millimeter Wave Antenna Solution and System", accepted by IEEE MTTS International Microwave Symposium, IMS 2014, Tampa Bay, Florida, US, 1-6 June 2014.

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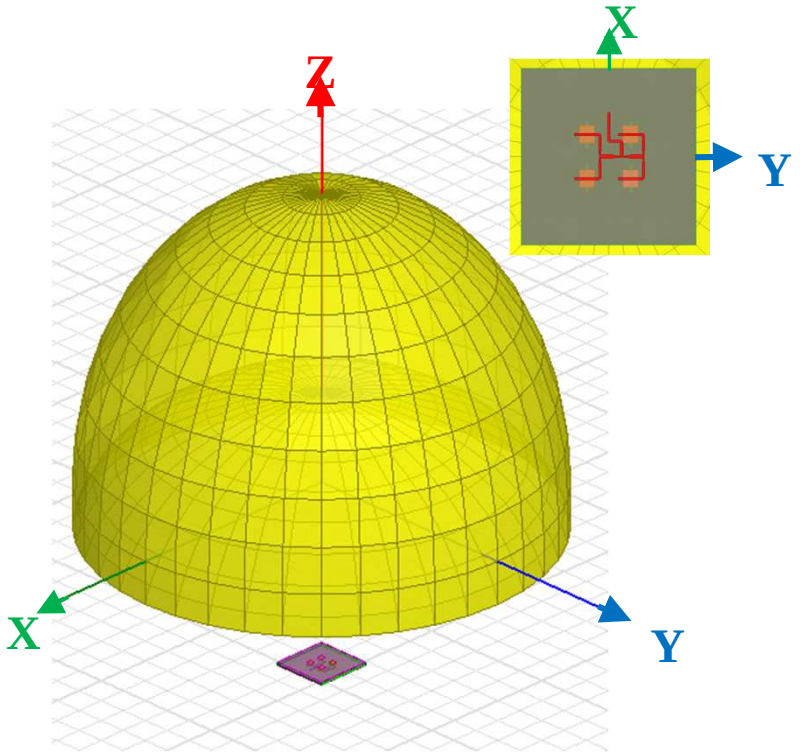
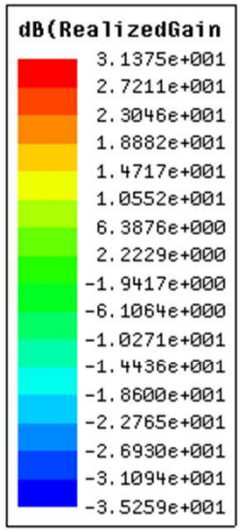
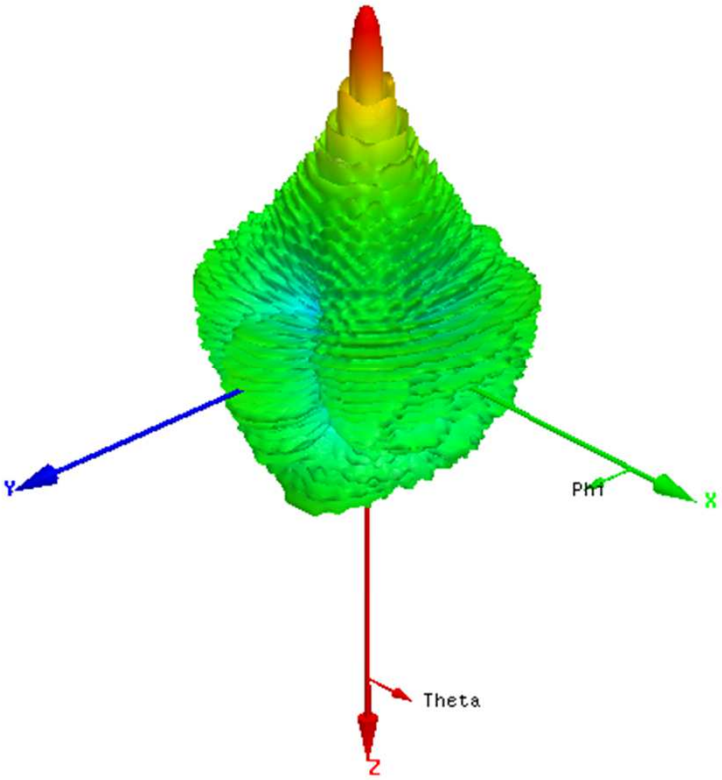
Low Cost and 3D Printed 60 GHz Plastic Lenses

- A *chopped hemispherical lens* (8 cm diameter) has then been *simulated* using a *2 x 2 antenna array* n low loss *PCB* as *source* in order to achieve *30 dBi gain*.







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Conclusion & Perspectives

- The development of denser networks using *small cell* (seamlessly integrating LTE and WiFi) is the *key* point of future *5G networks*
- To support this vision, *mmW wireless backhaul / fronthaul* will be a *key enabler* since optical solution deployment will not comply with *5G HetNets cost requirement*.
- *Silicon technologies* can here clearly *play a key role* in order to *push integration further* but this vision can emerged only *if low cost high gain mmW antenna* solution are proposed.
- While *V band* and *E band* can address *current* data rate *requirements* (up to 10 GbE), it makes a lot of sense to *investigate* frequencies band *>100 GHz* in order to offer low power, cost effective and higher data rates (*40 Gb/s*) *point to point communication*:
  - 20 GHz of bandwidth available @ *120 – 140 GHz*
  - 80 GHz of bandwidth available @ *200 – 280 GHz*

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Thank you for you attention!

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